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**NEW UTILITY PATENT APPLICATION  
TRANSMITTAL***(Only for new nonprovisional applications under 37 C.F.R. 1.53(b))*Docket No.  
Broutin 31-35-50  
Total pages in this  
submission**TO THE ASSISTANT COMMISSIONER FOR PATENTS****Box Patent Application  
Washington, D.C. 20231**

Transmitted herewith for filing under 35 U.S.C. 111(a) and 37 C.F.R. 1.53(b) is a new utility patent application for an invention entitled:

FEEDBACK CONTROL LOOP OPERATING SYSTEM FOR TUNABLE SOURCE

and invented by:

Scott L. Broutin, James K. Plourde and John W. Stayt

**IF A CONTINUATION APPLICATION**, check appropriate box and supply requisite information:

- ☐ Continuation      ☐ Divisional  
☐ Continuation-in-part (CIP) of prior application No.: \_\_\_\_\_

Enclosed are:

**Application Elements**

1. ☒ Filing fee as calculated and transmitted as described below
2. ☒ Specification having 19 pages(s) and including the following:
  - a. ☒ Descriptive title of the invention
  - b. ☐ Cross references to related applications *(if applicable)*
  - c. ☐ Statement regarding Federally-sponsored research/development *(if applicable)*
  - d. ☐ Reference to microfiche appendix *(if applicable)*
  - e. ☒ Background of the invention
  - f. ☒ Brief summary of the invention
  - g. ☒ Brief description of the drawings *(if drawings filed)*
  - h. ☒ Detailed description
  - i. ☒ Claims as classified below
  - j. ☒ Abstract of the disclosure

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**Application Elements (continued)**

3. ☒ Drawing(s) (when necessary as prescribed by 35 U.S.C. 113)  
☐ Formal ☒ Informal Number of sheets: 3
4. ☒ Oath or Declaration  
a. ☒ Newly executed (original or copy) ☐ Unexecuted  
b. ☐ Copy from a prior application (37 C.F.R. 1.63(d) (for continuation/divisional applications only)  
c. ☒ With Power of Attorney ☐ Without Power of Attorney
5. ☐ Incorporation by reference (usable if Box 4b is checked)  
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.
6. ☐ Computer program in microfiche
7. ☐ Genetic sequence submission (if applicable, all must be included)  
a. ☐ Paper copy  
b. ☐ Computer readable copy  
c. ☐ Statement verifying identical paper and computer readable copies

**Accompanying Application**

8. ☒ Assignment papers (cover sheet & document(s))
9. ☐ 37 C.F.R. 3.73(b) statement (when there is an assignee)
10. ☐ English translation document (if applicable)
11. ☐ Information Disclosure Statement/PTO-1449 ☐ Copies of IDS citations
12. ☐ Preliminary Amendment
13. ☒ Acknowledgment postcard
14. ☐ Certified copy of priority document(s) (if foreign priority is claimed)
15. ☐ Certificate of Mailing  
☐ First Class ☐ Express Mail (Label No.: \_\_\_\_\_ )
16. ☐ Small Entity statement(s) -- # submitted \_\_\_\_\_ (if Small Entity status claimed)

**Accompanying Application (continued)**

- 17.
- ☐
- Additional enclosures (please identify below):

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**Fee Calculation and Transmittal**

The filing fee for this utility patent application is calculated and transmitted as follows:

☒ Large Entity☐ Small Entity

CLAIMS AS FILED						
For	# Filed	# Allowed	# Extra	Rate	Fee	
Total Claims	20	- 20 =		x \$18.00		
Independent Claims	4	- 3 =	1	x \$78.00	\$78.00	
Multiple Dependent Claims (check if applicable)					<input type="checkbox"/>	
Other Fees (specify purpose): Recordation Form Cover Sheet						\$40.00
BASIC FEE						\$690.00
TOTAL FILING FEE						\$708.00

☐ A check in the amount of \_\_\_\_\_ to cover the total filing fee is enclosed.☒ The Commissioner is hereby authorized to charge and Deposit Account No. 12 - 2325 as described below. A duplicate copy of this sheet is enclosed.☒ Charge the amount of 708.00 as filing fee.☒ Credit any overpayment.☒ Charge any additional filing fees required under 37 C.F.R. 1.16 and 1.17.☐ Charge the issue fee set in 37 C.F.R. 1.18 at the mailing of the Notice of Allowance, pursuant to 37 C.F.R. 1.31(b).Dated: September 29, 2000

Mark J. Thronson  
Attorney Reg. No.: 33,082  
Dickstein Shapiro Morin & Oshinsky LLP  
2101 L Street NW  
Washington, DC 20037-1526  
(202) 785-9700

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE  
APPLICATION FOR U.S. LETTERS PATENT

Title:

**FEEDBACK CONTROL LOOP OPERATING  
SYSTEM FOR TUNABLE SOURCE**

Inventors:

Scott L. Broutin  
James K. Plourde  
John W. Stayt, Jr.

Dickstein Shapiro Morin &  
Oshinsky LLP  
2101 L Street, N.W.  
Washington, D.C. 20037  
(202) 785-9700

## BACKGROUND OF THE INVENTION

The present invention relates generally to systems for operating, stabilizing and/or controlling tunable light sources, for use for example in communications systems. The present invention also relates to a digital software-based system with multiple control loops for controlling a laser device, such as a distributed Bragg reflector (DBR) device.

## DESCRIPTION OF THE RELATED ART

Analog-based systems, with ultra-fast control loops operating inside of other loops, have been suggested for use in controlling DBR laser devices. Such analog-based systems lack the flexibility of digital control systems, however. Moreover, the analog-based systems do not provide the ability to fully automate the control process via operating software.

Multi-parameter control (wavelength, mode-hop avoidance, power and optical amplifier gain) of DBR lasers presents two fundamental problems. The first is that, to mode-stabilize a DBR device, the output from the backface must be monitored during ramping of the current to the tuning section. The ramping of the tuning current tends to alter the output wavelength, which is undesirable. The other problem is that ramping of the tuning current affects the amplitude detected by the backface monitor. The characteristics of these changes are fundamental to proper mode stabilization. Any changes, either deliberate or due

to aging effects, in the current to the gain section of the device will also produce changes at the backface that could be interpreted as actual changes in the tuning section. There is a need in the art for a digital feedback control system, with nesting and interaction between the various control functions, that can provide a complete DBR operating control solution.

### SUMMARY OF THE INVENTION

The present invention relates to a method of operating a distributed Bragg reflector (DBR) laser device. The method includes the steps of using a first feedback loop to periodically adjust the temperature (or another wavelength-related characteristic) of the laser device in response to a sensed wavelength, and using a second feedback loop to periodically adjust the tuning current in response to sensed amplitude. If desired, the two feedback loops may be operated at the same time.

The present invention also relates to a method of starting-up a tunable light source (such as a DBR light source). According to this aspect of the invention, a tuning current value is calculated based on stored data representative of mode-hopping values for the light source. The stored data may be maintained in a look-up table, for example. In a preferred embodiment, the wavelength channel may be changed by applying a tuning current that is based on the same stored mode-hopping data.

The present invention also relates to a system for stabilizing the output of a laser device. The system operates by adjusting a tuning current in response to output power, and simultaneously adjusting a wavelength characteristic of the device (e.g., temperature) in response to an optically filtered fraction of the output power.

An advantageous feature of the present invention is that numerous operational parameters for a DBR laser device can be simultaneously controlled and stabilized. In a preferred embodiment, an intelligent interaction of the feedback control loops is used to achieve the desired stabilization of multiple parameters in a software-driven closed-loop feedback system.

According to yet another aspect of the invention, an etalon temperature loop is nested within a tuning current loop and a power control loop. The tuning current loop may be used to control the side mode suppression ratio (SMSR) or some other operational parameter. The power control loop may be operated based on the amplitude detected by a backface monitor. This arrangement may be suitable for operating and/or stabilizing a two-section DBR laser device (i.e., one that has tuning and gain sections only).

According to another aspect of the invention, the power control loop may be operated based on the output power of a semiconductor optical amplifier (SOA). In this case, the tuning current loop may be nested within the power control loop, and the temperature loop may be nested within the tuning current loop. This arrangement may be suitable for operating and/or stabilizing a four-section DBR laser device (tuning, gain, optical amplifier and modulator sections).

An object of the invention is to provide a digital control system that can be flexibly adjusted for changes in operating parameters and the like via software control.

## BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages and features of the invention will become more apparent from the detailed description of preferred embodiments given below with reference to the accompanying drawings, in which:

FIG. 1 is a schematic view of a feedback control loop operating system constructed in accordance with one aspect of the present invention.

FIG. 2 illustrates the software-based nesting and interaction of the control loops for the system of FIG. 1.

FIG. 3 is a schematic view of a system constructed in accordance with another aspect of the present invention.

FIG. 4 illustrates the nesting and interaction of the control loops for the system of FIG. 3.

FIG. 5 is a schematic view of yet another operating system constructed in accordance with the present invention.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, where like reference numerals designate like elements, there is shown in FIG. 1 a system 10 for operating a tunable, distributed Bragg reflector (DBR) laser device 12. The laser device 12 may be arranged to generate a light output at any one of a plurality of center wavelengths (for example, the channel wavelengths of a dense wavelength division multiplexing (DWDM) communications system), under the control of a microprocessor 14. The light output of the laser device 12 is launched into a



suitable optical communications fiber 16, and from there into a suitable communications node or other device 18, for use in the communications system as desired.

The illustrated laser device 12 has at least two monolithic, optically coupled sections arranged in tandem, namely, a DBR tuning section and a gain section. In addition, the device 12 has a temperature sensor 20 and a thermoelectric cooler (TEC) 22. The temperature sensor 20 and the TEC 22 may be thermally coupled to the DBR tuning and gain sections. The TEC 22 may be used to control the temperature of the laser device 12, to thereby affect the wavelength of the output light (16) as discussed in more detail below.

The microprocessor 14 receives various input signals 24, 26, 28, 30 from a remote input device (not shown), a wavelength discriminator 32, the temperature sensor 20, and a backface monitor 34, respectively. The microprocessor 14 provides an output signal 36 to control the TEC 22. In addition, the microprocessor 14 provides output signals 38, 40 to suitable current sources 42, 44, such that tuning and gain currents  $I_{\text{tune}}$ ,  $I_{\text{gain}}$  are supplied to the DBR tuning and gain sections of the laser device 12, respectively.

In operation, the remote input device (not shown) is used to apply a start-up signal 24 to the microprocessor 14. The input signal 24 corresponds to a selected start-up wavelength or channel. In response, the microprocessor 14 determines a start-up tuning current  $I_{\text{tunc}}$  with reference to a suitable look-up table 50. In the illustrated embodiment, the look-up table 50 contains data representative of tuning currents at which DBR mode-hopping would occur. The microprocessor 14 proceeds to look up the tuning currents  $I_{\text{upper}}$ ,  $I_{\text{lower}}$  that bound the selected start-up wavelength, and then sets the tuning current  $I_{\text{tunc}}$  at a calculated value between the two bounding currents  $I_{\text{upper}}$ ,  $I_{\text{lower}}$ .

Thus, in a preferred embodiment of the invention, the tuning current  $I_{\text{tune}}$  initially applied to the DBR tuning section of the laser device 12 is defined according to the following expression (equation (1)):

$$(1) \ I_{\text{tune}} = ((I_{\text{upper}} - I_{\text{lower}})/3) + I_{\text{lower}}$$

where  $I_{\text{upper}}$  and  $I_{\text{lower}}$  are the two mode-hopping tuning currents stored in the look-up table 50, immediately above and below the selected start-up wavelength. The present invention should not be limited, however, to the details of the preferred embodiments shown and described herein. In particular, the number “3” in equation (1) could be various other numbers or parameters. If desired, the number could be correlated to the exact ITU grid channel.

At the same time, a lower limit  $I_{\text{limit}}$  may be set for the tuning current  $I_{\text{tune}}$ , for use during operation of the tuning current loop 52 (FIG. 2). The tuning current loop 52 may contain software that is programmed to prevent the tuning current  $I_{\text{tune}}$  from becoming lower than a “dangerous” value during slope determination, to prevent unacceptable degradation of the side mode suppression ratio (SMSR) or a mode. Thus, the tuning current  $I_{\text{tune}}$  applied to the DBR tuning section of the laser device 12 is maintained greater than or equal to the lower limit  $I_{\text{limit}}$ .

In a preferred embodiment of the invention, the lower limit  $I_{\text{limit}}$  may be set, for example, according to equation (2) as follows:

$$(2) \ I_{\text{limit}} = 1.05 * I_{\text{lower}}$$

such that the factor of safety is 5% of the lower mode-hopping current  $I_{\text{lower}}$  bounding the selected start-up wavelength, according to the data in the look-up table 50. As noted above, however, the present invention should not be limited

to the preferred embodiments shown and described in detail herein. An advantage of the present invention is that relationships such as equations (1) and (2) may be readily changed by modifying the software code stored in the microprocessor 14 as needed to accommodate the particular mode/output characteristics of the laser device 12. The software also may be changed over time (e.g., the look-up table 50 may be updated), if desired, to accommodate for aging of the laser device 12 and/or other components.

The temperature loop 54 (FIG. 2) for the system 10 includes the discriminator 32 (FIG. 1) and the TEC 22 (controlled by the software-based operation of the microprocessor 14). In the illustrated embodiment, the temperature loop 54 is engaged and operated at the same time as the start-up tuning current  $I_{\text{tune}}$  is applied to the laser device 12. The temperature loop 54 is used to lock the output light (16) of the laser device 12 at a stable wavelength. The temperature loop 54, whose software is operationally nested within the tuning current loop 52 and a power control loop 56 as shown in FIG. 2, operates as follows:

The discriminator 32 generates a signal 26 representative of the wavelength of the output light in the fiber 16. The discriminator 32 may be connected to the optical fiber 16 by a suitable tap 58 of the type shown in U.S. Patent No. 6,064,681 (Ackerman), the entire disclosure of which is incorporated herein by reference. The microprocessor 14 sends a signal 36 to the TEC 22 to adjust the temperature of the laser device 12 to bring the sensed wavelength (at the tap 58) in line with the desired wavelength. The temperature loop 54 is updated periodically according to a clock in the microprocessor 14 such that the wavelength sensing and corresponding temperature updating occurs essentially continuously.

In a preferred embodiment of the invention, the temperature loop 54 is operated at an update rate that is ten to thirty times faster (depending on the  $I_t$  increment and mode being worked) than the update rate of the tuning current loop 52 (discussed in more detail below). In the embodiment shown in FIG. 2, the temperature loop 54 must be operated whenever the tuning current loop 52 is engaged, to thereby hold the output wavelength at the tap 58 within acceptable locking specifications.

The tuning current loop 52 is made up of the backface monitor 34 and the tuning current source 42 (operated under the control of output signal 38 from the microprocessor 14). The tuning current loop 52 operates to adjust, control and/or optimize the tuning current  $I_{tune}$  as a function of the power or amplitude at the laser device backface 60, as detected by the backface monitor 34.

During an initial portion of the start-up phase, while the temperature loop 54 is operating, the tuning current loop 52, under the control of suitable software in the microprocessor 14, performs a ramping up and down of the tuning current  $I_{tune}$ . In particular, the microprocessor 14 alternately adjusts the output signal 38 up and down to effectively “walk” up and down a curve representing the relationship between the backface amplitude (60) and the applied tuning current  $I_{tune}$ , for the operating mode. During the “walking” operation, the tuning current loop 52 generates point-by-point data representative of the sensed relationship between the backface amplitude (60) and the applied tuning current  $I_{tune}$ .

As the data is generated and accumulated during the “walking” phase, local slope values representative of backface amplitude as a function of tuning current are calculated, and the slope values  $dP/dI$  are stored in a suitable memory location 62 in the microprocessor 14. The temperature loop 54 is

operated throughout the generation of the slope data (62), such that the device output (16) is maintained at a fixed wavelength, and then a desired locking slope value is determined based on the stored data (62).

5           Once a value equal to or close to the desired locking slope value is defined by the microprocessor 14, an optimized tuning current  $I_{\text{tune}}$  is output to the DBR tuning section to hold the laser device 12 in the neighborhood of the desired locking slope value, at a point dependent on the percentage of the mode width that was used to scan and determine the slope value during the “walking” phase.  
10       In a preferred embodiment of the invention, the scanning range is set at 5% of the mode width, but other scanning percentages may be programmed into the microprocessor 14 to accommodate other values that are considered safe with respect to mode-hopping, relative to predetermined locking requirements. The locking requirements may be determined based in part on a desired signal-to-  
15       noise ratio (S/N) for the system 10.

          Once the above-described initialization operations are completed, the tuning current loop 52 may be disengaged, and then the power control loop 56 may be engaged to apply sufficient gain current  $I_{\text{gain}}$  to the laser device 12 to  
20       bring the backface power (sensed by the monitor 34) up to a constant level without causing a mode-hop in the device 12. The power control loop 56 adjusts the gain current  $I_{\text{gain}}$  in response to the signals 30 from the backface monitor 34. The start-up phase is completed when the backface power (60) is brought up to the desired, constant level. In the illustrated system 10, if the  
25       tuning current  $I_{\text{tune}}$  were not properly set prior to engaging the power control loop 56, then an increase in the current  $I_{\text{gain}}$  applied to the gain section of the device 12 could force a mode-hop despite operation of the temperature loop 54 (e.g., due to local heating). Consequently, in the system 10 shown in FIG. 1, it is advantageous to operate the tuning current loop 52 before the power control  
30       loop 56 is first engaged by the microprocessor 14.

After the above-described start-up phase is completed, the system 10 may be operated in a channel lock mode. In the channel lock mode, the tuning current loop 52 only needs to be engaged from time to time. That is, the tuning current loop 52 may be used to adjust the tuning current  $I_{\text{tune}}$  only during such times as when the backface monitor 34 senses that the device 12 has shifted into a less than ideal SMSR position.

The tuning current loop 52 may be activated while the power control loop 56 adjusts the gain current  $I_{\text{gain}}$ . In the embodiment shown in FIG. 3, although the gain section of the device 104 is relied upon to hold a constant power output on line 16, it is not necessary to shut down the power control loop 56 during ramping of the tuning current loop 52. Since both loops 52, 56 respond to signals 30 from the same monitor 34, however, the time-constraints for the two loops 52, 56 may have to be set appropriately to prevent them from interacting with each other. If a very slow tuning current loop 52 is employed, it may be preferable to completely disengage the power control loop 56 during operation of the tuning current loop 52. In any event, the temperature loop 54 may be operated at all times to maintain the desired wavelength lock.

In a preferred embodiment of the invention, there is enough slope in each operational wavelength curve to allow a  $\frac{1}{2}$ -channel definition via an etalon and temperature, and it appears that laser tuning via the temperature loop 54 does not shift the applicable tuning current curves relative to the wavelength curves. Thus, by using an appropriate control sign inversion --  $((\text{REF} - \text{ETALON})/\text{REF})$  vs.  $((\text{ETALON} - \text{REF})/\text{REF})$  -- it is possible to lock the wavelength of the light output (16) on the opposite slopes of a 100 GHz etalon. This, with an appropriate calibration, would make it possible to achieve a 50 GHz channel spacing for the device 12.

According to yet another aspect of the invention, full channel changes may be accomplished via the same look-up table method described above in connection with the start-up phase. Moreover, once a channel tuning slope  $dP/dI$  has been defined during a prior channel change, it is stored in the second memory location 62. When the system 10 later returns to that channel, a stable tuning current  $I_{\text{tune}}$  may be applied immediately to the laser device 12, by referring to the memory 62, to maintain the desired SMSR and to avoid a mode-hop.

Prior to an actual channel change, a changed current  $I_{\text{change}}$  may be abruptly applied to the gain section of the device 12, via the second current source 44, to help ensure that the operational gain current  $I_{\text{gain}}$  has not redefined the tuning current  $I_{\text{tune}}$  that defines the point of mode-hop. The changed current  $I_{\text{change}}$  may be defined empirically as follows (equation (3)):

$$(3) \ I_{\text{change}} = (I_{\text{gain}} \pm 4) * \Delta_{\text{channel}}^2,$$

where  $I_{\text{change}}$  is the current applied abruptly to the laser device 12,  $I_{\text{gain}}$  is the current applied to the gain section of the device 12 before the abrupt change, and  $\Delta_{\text{channel}}$  is the difference between the number of the then-operating channel and the number of the channel to which the laser device 12 is to be changed.

The system 100 shown in FIG. 3 has a semiconductor optical amplifier (SOA) 102. In the illustrated system 100, the amplitude signal for the power control loop 106 (FIG. 4) is received via a suitable tap 108 at the output 110 of the SOA 102, rather than at the backface of the laser device 104. Since the tuning current loop 52 and the power control loop 106 have different inputs (the backface monitor 34 and the in-line tap 108, respectively), the tuning current loop 52 may be operationally nested entirely within the power control loop 106. That is, the tuning current loop 52 may be operated by the

microprocessor 14 whenever the power control loop 106 is engaged. In addition, the software for the system 100 may be provided with a backface loop 108 for compensating for device aging effects. The backface loop 108 may be operated based on amplitude signals 30 provided by the backface monitor 34.

5 The system 100 (FIG. 3) is otherwise the same as the system 10 shown in FIG. 1. In both systems 10, 100, the temperature loop 54 is operationally nested within the tuning current loop 52 (by suitable software stored in the processor 14).

10 Turning now to FIG. 5, there is shown yet another digital processing system 200 for operating a laser device 12. The illustrated device 12 may have a wide wavelength tuning range. Consequently, the system 200 is provided with suitable feedback loops to correct for the effects of laser device aging, among other things. In particular, the system 200 has a tuning current loop that is

15 arranged to maintain a desired relationship between the light output power  $P$  and the tuning current  $I_{\text{tune}}$ , as follows (equation (4)):

$$(4) \ k = dP/dx,$$

20 where  $k$  is a slope constant,  $P$  is the power output by laser device 12,  $x = \log(I_{\text{tune}})$ , and  $I_{\text{tune}}$  is the corresponding tuning current applied to the DBR tuning section of the device 12.

25 Attempting to measure the slope constant  $k$  for equation (4) would be problematic in the prior art, since it would be measured by varying (or dithering) the tuning current  $I_{\text{tune}}$ , and since varying the tuning current  $I_{\text{tune}}$  could cause an unwanted optical or wavelength shift in the laser device 12. For example, varying  $x (= \log(I_{\text{tune}}))$  by 10% could cause a change in the operational wavelength  $\Delta\lambda/\lambda$  of about 50 ppm, which exceeds typical wavelength stability

30 requirements. Note that  $d\lambda/dx$  is approximately constant for the laser device 12,



whereas  $d\lambda/dI_{\text{tune}}$  varies widely. The latter value,  $d\lambda/dI_{\text{tune}}$ , may be approximately equal to  $d\lambda/dx * (0.4343)/I_{\text{tune}}$ .

The system 200 shown in FIG. 5 overcomes the problem of wavelength shifting caused by variations in the tuning current  $I_{\text{tune}}$  by employing a two-path wavelength control method, with appropriate bandwidth. Thus, the illustrated embodiment may be able to correct for the effects of variation in both optical power and wavelength caused by variations in the tuning current  $I_{\text{tune}}$ , and the present invention may be used to meet the tight wavelength stability specifications contemplated for DWDM communications systems. In particular, the present invention makes it possible to provide the tuning signal  $I_{\text{tune}}$  required for DBR laser operation without significantly degrading the wavelength control.

The illustrated system 200 obtains a reference voltage  $V_{\text{ref}}$  and a filtered voltage  $V_1$  based on power transmitted through a reference tap 210 and a filtered tap 212, respectively. After normalization (and ignoring noise which is small), a voltage ratio  $C(f)$  is calculated in the processor 14 as follows (equation (5)):

$$(5) \ C(f) = V_1/V_{\text{ref}}$$

where  $C(f)$  is the transmission fraction through the optical filter 214 in the filtered tap 212,  $f$  is the desired optical frequency, and for simplicity the two paths 210, 212 are assumed to be identical. The tuning current loop in the FIG. 5 system is based on the reference voltage  $V_1$ . That is, the tuning current  $I_{\text{tune}}$  is periodically adjusted based on changes in the optical power  $P$  sensed at the reference tap 210, under the control of the microprocessor 14. The temperature loop is based on the transmission fraction  $C(f)$ . In other words, the temperature of the TEC 22 is adjusted based on the normalized difference between the power  $P$  sensed at the reference tap 210 and the power sensed after the filter 214 in the filtered tap 212. Accordingly, the change in optical power that results from

dithering the tuning current (i.e.,  $\Delta I_{\text{tune}}$ ) can be normalized out as far as wavelength control and the temperature loop is concerned.

Still,  $d\lambda/dI_{\text{tune}}$  remains and is unwanted. In the illustrated embodiment, the significant effect of  $d\lambda/dx$ , or equivalently,  $d\lambda/dI_{\text{tune}}$ , is overcome by making the tuning current loop fully interactive with the temperature loop. With such loop interaction, the wavelength  $\lambda$  of the light output (16) is maintained constant by the temperature loop, even as the tuning current  $I_{\text{tune}}$  is varied by the tuning current loop. To accomplish the desired interaction, the bandwidth of the temperature loop may be significantly higher than that of the tuning current loop. The bandwidth difference permits the temperature loop to track and correct for wavelength changes introduced by changes in the tuning current  $I_{\text{tune}}$ .

To provide a rapid wavelength change (when requested via a signal 24 from the remote input device), a separate  $I_{\text{tune}}$  time constant may be switched in digitally during times of wavelength change requests. Such wavelength change requests may be accomplished by supplying a suitable signal on input line 24.

While the optical power variations discussed above should not affect the operation of the temperature loop, they may be “seen” by the system 200 if they are significant. Moreover, the loop interactions described above may introduce an error in the slope measurement that may have to be verified as acceptable. If desired, the optical power slope may be measured at two different temperatures where temperature is used to hold the output wavelength constant.

While preferred embodiments of the invention have been described and illustrated, it should be apparent that many modifications can be made to the preferred embodiments without departing from the spirit or scope of the present invention. Accordingly, the invention is not limited by the foregoing description or drawings, but is only limited by the scope of the appended claims.

[illegible]

1. A method of operating a distributed Bragg reflector laser device, said method comprising the steps of:

using a first feedback loop to periodically adjust a characteristic of said laser device in response to a sensed wavelength; and

5 using a second feedback loop to periodically adjust a current applied to said laser device in response to a sensed amplitude, and wherein said step of using said second feedback loop occurs during said step of using said first feedback loop.

10 2. The method of claim 1, further comprising the step of affecting the temperature of said laser device in response to said sensed wavelength.

15 3. The method of claim 2, further comprising the step of using a third feedback loop to adjust a gain current applied to a gain section of said laser device.

4. The method of claim 3, further comprising the step of operating said third feedback loop in response to said amplitude.

20 5. The method of claim 4, wherein said step of using said third feedback loop occurs during said step of using said first feedback loop.

25 6. The method of claim 2, further comprising the step of using a third feedback loop to operate an amplifier associated with said laser device.

7. The method of claim 6, further comprising the step of operating said third feedback loop in response to the output power of said amplifier.

30 8. The method of claim 7, wherein said step of using said third feedback loop occurs during said step of using said second feedback loop.

9. The method of claim 2, further comprising the step of calculating transmission fraction data based on a reference power output and a filtered power output.

5           10. The method of claim 1, further comprising the step of using a backface loop to compensate for aging, said backface loop being operated based on signals from a backface monitor.

10           11. A method of starting-up a tunable light source, said method comprising the steps of:

            providing data in a memory representative of mode-hopping values for said tunable light source;

            with reference to said data, calculating a value representative of a tuning current for said tunable light source; and

15           applying said tuning current to said tunable light source.

20           12. The method of claim 11, further comprising the step of adjusting the temperature of said tunable light source, and wherein said step of applying said tuning current occurs during said step of adjusting the temperature of said tunable light source.

            13. The method of claim 12, further comprising the step of storing curve data in a memory.

25           14. The method of claim 13, further comprising the step of applying a second tuning current signal to said tunable light source as a function of said curve data.

15. A method of changing the wavelength channel of a laser device, said method comprising the steps of:

operating said laser device at a first wavelength; and

applying a tuning current to said laser device as a function of a second wavelength and mode-hopping data stored in a memory, said second wavelength being different than said first wavelength.

16. The method of claim 15, wherein said step of applying said tuning current includes the step of reading curve data from a memory.

17. The method of claim 15, further comprising the step of using a thermo-electric cooler to control the temperature of said laser device, and wherein said thermo-electric cooler is operated by a digital feedback loop.

18. The method of claim 15, further comprising the step of monitoring the amplitude developed at the backface of the laser device.

19. A method of stabilizing a laser device, said method comprising the steps of:

adjusting a tuning current applied to said laser device in response to output power; and

simultaneously, adjusting a wavelength characteristic of said laser device in response to an optically filtered transmission fraction of said output power.

20. The method of claim 29, wherein said adjusting steps are performed by a programmed microprocessor.

ABSTRACT

5 Multiple operational parameters for a laser device are simultaneously controlled, optimized and/or stabilized by a software-based system with nested and interactive feedback control loops. Start-up mode, channel lock mode and channel change mode operations are described. The invention may be applied to a laser device with monolithic DBR tuning and gain sections, and also to systems with separate amplifiers. An optical filter system for normalizing-out changes in output power in relation to wavelength control is also disclosed.

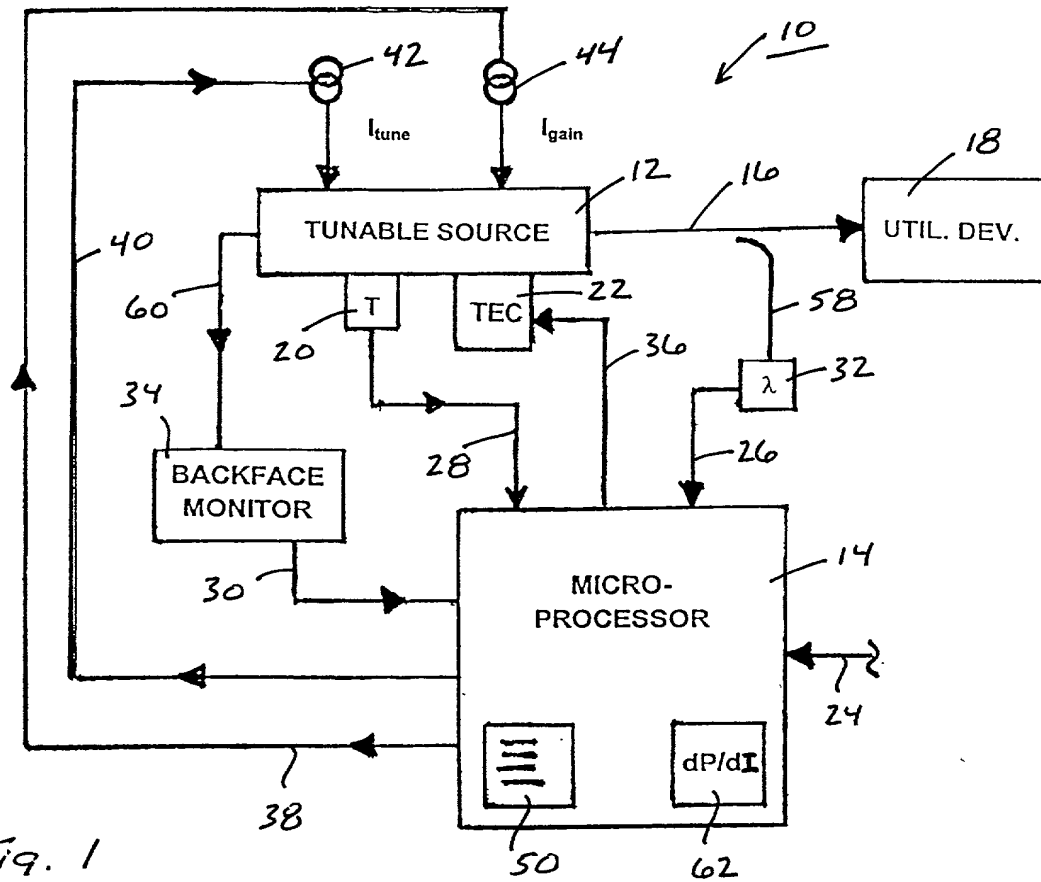


Fig. 1

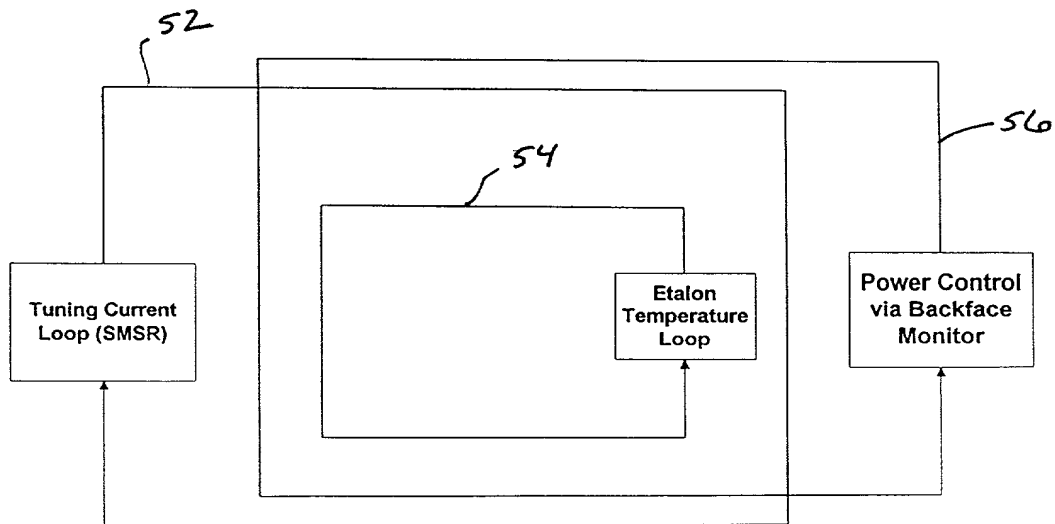


Fig. 2



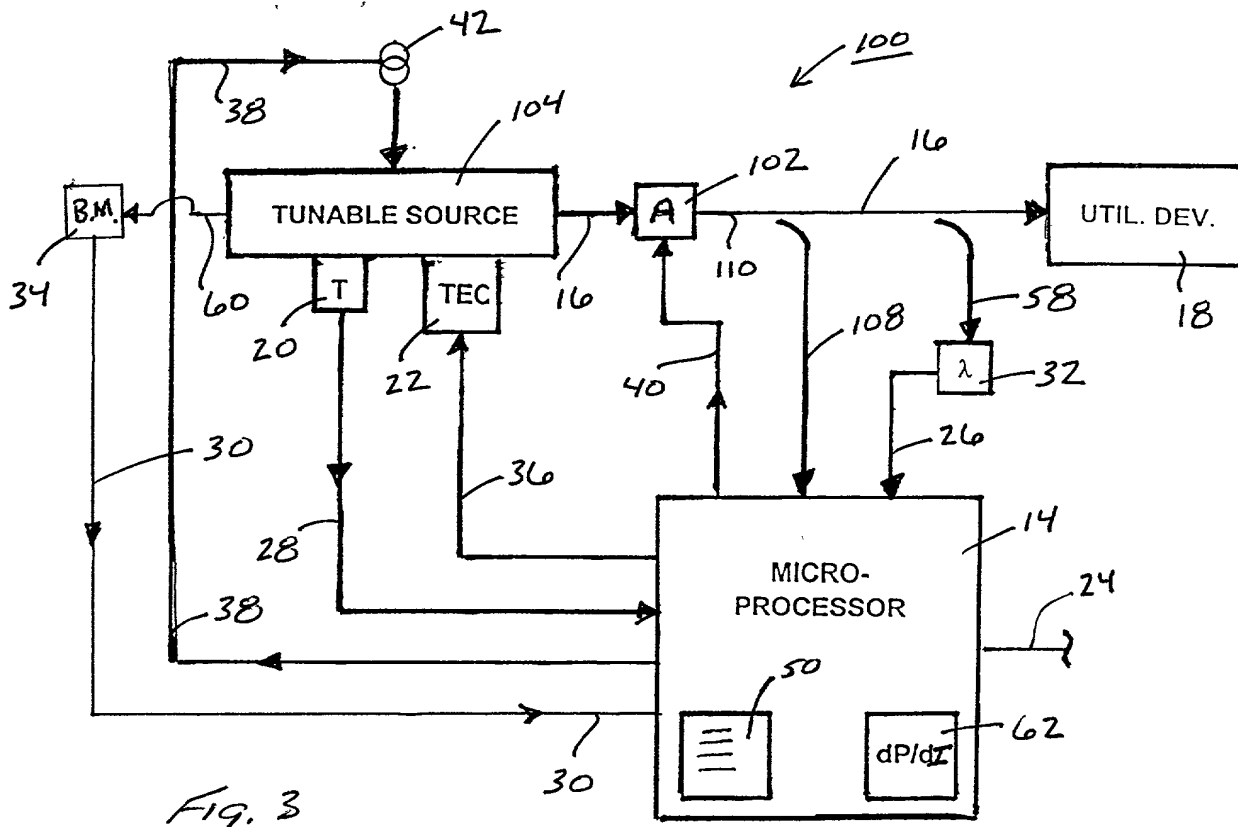


Fig. 3

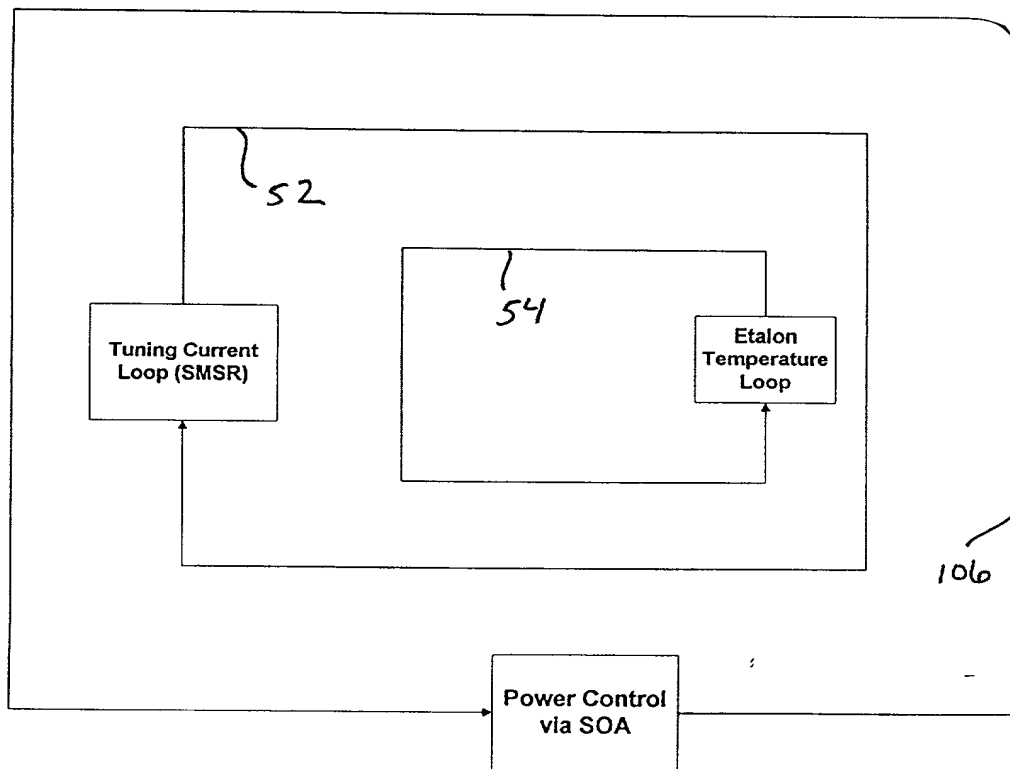


Fig. 4

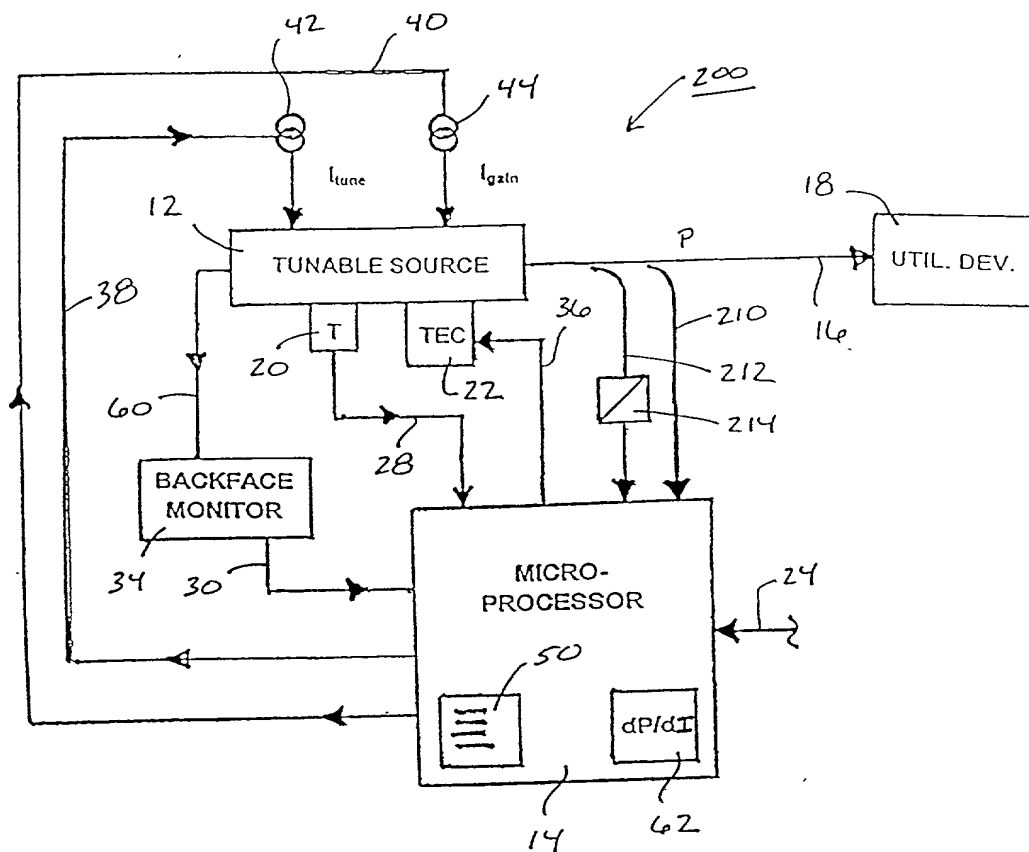


Fig. 5

Docket No.: 17480.0187  
BROUTIN 31-35-50IN THE UNITED STATES  
PATENT AND TRADEMARK OFFICE

## Declaration and Power of Attorney

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled FEEDBACK CONTROL LOOP OPERATING SYSTEM FOR TUNABLE SOURCE, the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by an amendment, if any, specifically referred to in this oath or declaration.

I acknowledge the duty to disclose all information known to me which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

None

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

None

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

I hereby appoint the following attorney(s) with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected therewith:

Attorney Name	Atty Registration Number
Thomas J. Bean	Reg. No. 44528
Lester H. Birnbaum	Reg. No. 25830
Richard J. Botos	Reg. No. 32016
Jeffery J. Brosemer	Reg. No. 36096
Kenneth M. Brown	Reg. No. 37590
Donald P. Dinella	Reg. No. 39961
Guy Eriksen	Reg. No. 41736
Martin I. Finston	Reg. No. 31613
William S. Francos	Reg. No. 38456
Barry H. Freedman	Reg. No. 26166
Julio A. Garceran	Reg. No. 37138
Jimmy Goo	Reg. No. 36528
Anthony Grillo	Reg. No. 36535
Stephen M. Gurey	Reg. No. 27336
John M. Harman	Reg. No. 38173
Matthew J. Hodulik	Reg. No. 36164
Michael B. Johannesen	Reg. No. 35557
Mark A. Kurisko	Reg. No. 38944
Irena Lager	Reg. No. 39260
John B. MacIntyre	Reg. No. 41170
Christopher N. Malvone	Reg. No. 34866
Scott W. McLellan	Reg. No. 30776
Martin G. Meder	Reg. No. 34674
John C. Moran	Reg. No. 30782
Michael A. Morra	Reg. No. 28975
Gregory J. Murgia	Reg. No. 41209
Claude R. Narcisse	Reg. No. 38979
Joseph J. Opalach	Reg. No. 36229
Neil R. Ormos	Reg. No. 35309
Eugen E. Pacher	Reg. No. 29964
Jack R. Penrod	Reg. No. 31864
Gregory C. Ranieri	Reg. No. 29695
Scott J. Rittman	Reg. No. 39010
Ferdinand M. Romano	Reg. No. 32752
Eugene J. Rosenthal	Reg. No. 36658
Bruce S. Schneider	Reg. No. 27949
Ronald D. Slusky	Reg. No. 26585

David L. Smith	Reg. No. 30592
Ozer M. N. Teitelbaum	Reg. No. 36698
John P. Veschi	Reg. No. 39058
David Volejnicek	Reg. No. 29355
Charles L. Warren	Reg. No. 27407
Jeffery M. Weinick	Reg. No. 36304
Eli Weiss	Reg. No. 17765

I hereby appoint the attorney(s) on ATTACHMENT A as associate attorney(s) in the aforementioned application, with full power solely to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected with the prosecution of said application. No other powers are granted to such associate attorney(s) and such associate attorney(s) are specifically denied any power of substitution or revocation.

Full name of first joint inventor: Scott L. Broutin

Inventor's signature  Date 9/25/2000

Residence: Kutztown, PA

Citizenship: United States of America

Post Office Address: 361 Grim Road  
Kutztown, PA 19530

Full name of second joint inventor: James K. Plourde

Inventor's signature  Date 9/25/2000

Residence: Allentown, PA

Citizenship: United States of America

Post Office Address: 114 N. Marshall Street  
Allentown, PA 18104

Full name of third joint inventor: John W. Stayt, Jr.

Inventor's signature X John W. Stayt, Jr. Date X 9/25/2000

Residence: Schneeksville, Pennsylvania

Citizenship: United States of America

Post Office Address: 4091 Kistler Road  
Schneeksville, PA 18078

**ATTACHMENT A**

Attorney Name	Atty Registration Number
Gary M. Hoffman	26,411
Thomas J. D'Amico	28,371
Donald A. Gregory	28,954
James W. Brady Jr.	32,115
Jon D. Grossman	32,699
Mark J. Thronson	33,082
Jeremy A. Cubert	40,399
Laurence E. Fisher	37,131
Brian A. Lemm	43,748
John F. Levis	34,210
Gianni Minutoli	41,198
Edwin Oh	P-45,319
Eric Oliver	35,307
William E. Powell III	39,803
Mark E. Strickland	45,138
Salvatore P. Tamburo	P-45,153

Telephone calls should be made to Thomas J. D'Amico at:

Phone No.: (202) 785-9700 Fax No.: (202) 887-0689

All written communications are to be addressed to:

Thomas J. D'Amico, Esq.  
DICKSTEIN SHAPIRO MORIN & OSHINSKY LLP  
2101 L Street NW  
Washington, DC 20037-1526